

## 29. MID-CRETACEOUS RADIOLARIANS FROM THE EASTERN EQUATORIAL ATLANTIC AND THEIR PALEOCEANOGRAPHY<sup>1</sup>

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### ABSTRACT

Distinct intervals from cores recovered at Holes 959D and 962B of Ocean Drilling Program Leg 159 have yielded Cretaceous radiolarians. The recovered faunas are of late Albian to uppermost Cenomanian (in intervals 159-962B-8H-4, 85–86 cm, to 159-962B-10H-CC), late Turonian to Santonian (in intervals 159-962B-8H-4, 2–4 cm, to 159-962B-8H-4, 24–28 cm) and Campanian age (Sections 159-959D-61R-1 through 3). Preservation of the faunas is moderate to poor. While the Campanian fauna generally reflect the typical low- to mid-latitude associations known from the North Atlantic and Alpine realm, mid-Cretaceous radiolarian assemblages show certain differences to those known from the North Atlantic and Tethys. The similarities of the observed faunas to those from the North Atlantic and Tethys seem to increase with the ongoing opening of the Equatorial Atlantic Gateway. Differences between the late Albian faunas of both basins are significant. All of the observed faunas are of a remarkably low diversity. The diversity and the similarity to Tethyan faunas increase toward the late Cenomanian. As very little knowledge exists about late Turonian to Santonian assemblages, comparisons between the observed fauna and their definite ages remain difficult.

Radiolarian-bearing intervals correlate well with the radiolarian-rich time intervals of other basins and, therefore, support former observations of a correlation of radiolarian intervals and mid-Cretaceous oceanic events. The observed radiolarian-rich intervals (late Albian, pre-Oceanic Anoxic Event [OAE] 1d; late Cenomanian, pre-OAE 2, and Campanian, OAE 3) correlate well with times of transgressive sea level.

### INTRODUCTION

The knowledge of mid-Cretaceous radiolarians has improved during the last 20 years because of many stratigraphic and taxonomic studies, as well as a few ecological studies. While most of them focused on radiolarians from the Tethys, Pacific, and North Atlantic (Pessagno, 1976; Pessagno, 1977; Schaaf, 1984; Thurow, 1988; Erbacher, 1994; O'Dogherty, 1994), hardly any data exist on faunas from the South Atlantic (Foreman, 1978; Ling and Lazarus, 1990). The recovery of mid-Cretaceous radiolarians during Leg 159 provides new information on the taxonomy, biogeography, and stratigraphy of radiolarians and gives new insights into the history of the opening of the Equatorial Atlantic Gateway.

This paper focuses on the preliminary results of my studies of Cretaceous radiolarians from Leg 159, specifically in the Albian to Coniacian (to Santonian?) assemblages.

### MATERIAL AND METHODS

Hole 962B (3°15.063'N, 3°10.919'W) has been drilled at a water depth of 4637 m. It is located at the base of the continental slope close to the Côte d'Ivoire-Ghana Marginal Ridge (Fig. 1). Cores 159-962B-8H through 10H have been sampled. Radiolarians appeared in Sections 159-962B-8H-4 through 8H-CC, in most of the samples of Core 159-962B-9H, and in the core catcher of Core 159-962B-10H (Table 1). An unconformity in Sample 159-962B-8H-4, 80 cm, separates a pale green glauconite-rich claystone from a pale green claystone with cherts. The latter lithology is strongly brecciated (because of drilling disturbances?) and continues to Section 159-962B-8H-

CC. Calcareous nannoplankton and planktonic foraminifers suggest the age of the breccia to be Albian to Cenomanian (Bellier, Chap. 27; Watkins et al., Chap. 26, both this volume). Core 159-962B-9H to Section 159-962B-10H-CC consists of dark cherts and pyrite-rich claystone also brecciated by coring. Benthic and planktonic foraminifers indicate a late Albian age (Bellier, Chap. 27; Holbourn and Moullade, Chap. 28, both this volume). The abundance of radiolarians is generally rare to common (Fig. 2). The preservation varies from very poor to moderate.

Sediment samples (10 cm<sup>3</sup>) were treated and broken down with distilled water. Clay-rich samples have been treated with a mixture of 50% anionic detergent (REWOQUAD) and 50% alcohol. Samples were washed over a 63- $\mu$ m net. The residue >63  $\mu$ m was analyzed, studied under a reflected light stereoscopic microscope, and photographed using the scanning electron microscope (SEM). For SEM, specimens have been mounted on SEM stubs with double sided tape and coated with platinum.

Relative abundances are based on population counts of the entire residue (Table 1): x = one specimen; r (rare) = from two to five specimens; f (few) = from six to 10 specimens; and c (common) = from 11 to 20 specimens.

### BIOSTRATIGRAPHY

Radiolarians from Cores 159-962B-8H through 10H were subdivided into three different intervals characterized by different preservation and radiolarian assemblages.

The first interval (159-962B-8H-4, 2–28 cm) reveals a fauna of moderate to poor preservation. Radiolarians are replaced by opal-CT and show overgrowth of zeolite (clinoptilolite) crystals (Fig. 2; T. Pletsch, pers. comm., 1996). The age of the assemblages is problematic. However, the lack of typical Campanian forms that were observed in Core 159-959D-61R (W. Kuhnt, pers. comm., 1996) and the absences of Cenomanian morphotypes, which appear downsection, indicate a late Turonian to Santonian age (Table 1). As little knowledge exists about radiolarians of Turonian to Santonian age, a

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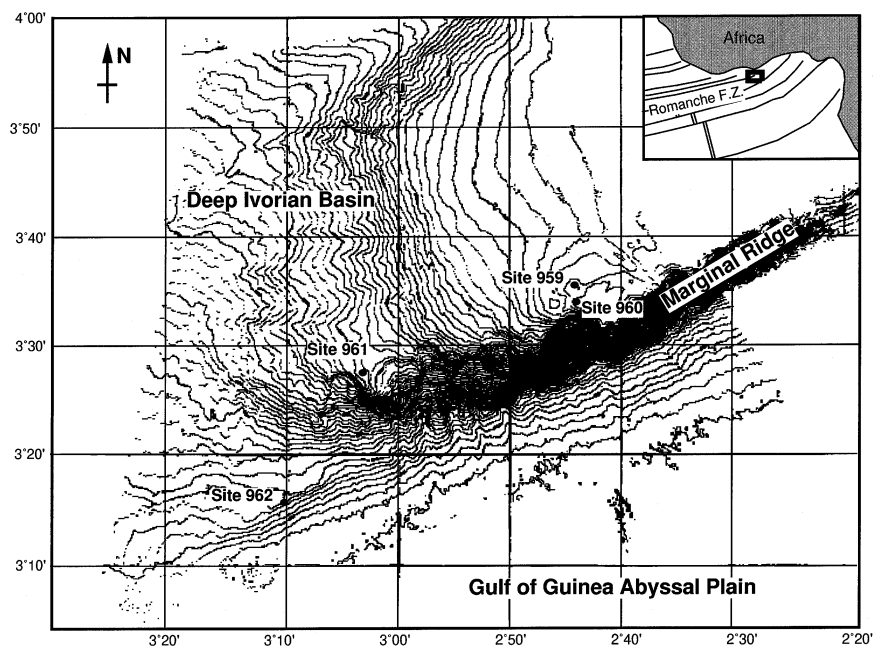


Figure 1. Location map of drilled sites of ODP Leg 159 showing the Côte d'Ivoire-Ghana Marginal Ridge and surrounding areas. Mid-Cretaceous radiolarians have been observed in Hole 962B (Basile et al., 1996).

clearer age assignment of this interval remains difficult. Species like *Vitorfus morini* and *Dictyomitra multicosata* have not been observed in sediments older than Turonian, but are known from the Campanian, too. *Dictyomitra densicostata* is known only from the Coniacian to the Campanian of California (Pessagno, 1976), *Dictyomitra nappaensis* has been described from the late Turonian to the late Coniacian of California (Pessagno, 1976), and forms like *Guttacapsa gutta* and *Rhopalosyringium hispidum* show similarities to mid-Cretaceous faunas (O'Dogherty, 1994), but have not, to my knowledge, been observed in Campanian sediments yet. As this fauna shows only few similarities to rather well known early Turonian and Campanian faunas, but does include elements of both of them, I tentatively place its assemblages into the Coniacian/Santonian.

The second interval (159-962B-8H-4, 65 cm, to 8H-CC) shows opal-CT replaced radiolarians. Most of the specimens are overgrown with fibrous palygorskite crystals (T. Pletsch, Chap. 15, this volume). Assemblages including forms like *Dactylosphaera lepta*, *Cavaspongia sphaerica*, *Stichomitra communis*, *Napora praespiniifera*, *Guttacapsa biacuta* and *Patellula verteroensis* have been described from sections in Italy, Spain, and the North Atlantic (Erbacher, 1994; O'Dogherty, 1994) (Table 1) and are parts of a fauna observed in the late Cenomanian (*Rotalipora cushmani* planktonic foraminifer zone, *Biacuta* radiolarian zone) of Central Italy (O'Dogherty, 1994). Even if the index taxon of the middle to late Cenomanian *Pseudodictyomitra nakasekoi* radiolarian zone described from the North Atlantic (Erbacher and Thurow, in press) could not be identified in the observed samples, many of the observed taxa from this interval are typical elements of this zone. However, some of the observed morphotypes differ from its Tethyan relatives in their morphology and/or stratigraphic range, and many common Tethyan or North Atlantic taxa and genera like *Pseudodictyomitra*, *Crolanium*, *Xitus*, *Novixitus*, and *Halesium* do not occur in the studied material. Among the forms that differ from their Tethyan and North Atlantic relatives and that may be regarded as South Atlantic ecophenotypes are the observed varieties of *Cavaspongia euganea*, *Cavaspongia sphaerica*, *Dactylosphaera lepta* and a species of the genus *Rhopalosyringium* resembling *R. euganeum* (for details see taxonomic notes).

Compared to the well-known radiolarian assemblages of the North Atlantic and Tethys, faunas from the eastern equatorial Atlantic are remarkably impoverished in diversity. Based on present information, some of the observed forms (e.g., *?Hisocapsa* sp.) seem to

be endemic and may be restricted to the northern South Atlantic or are of an austral origin.

The third interval (159-962B-9H-1 through 10H-CC) is again characterized by opal-CT-replaced radiolarians. The diversity of the fauna is very low; small to tiny forms are dominating the samples. The remarkable decrease in size from Core 159-962B-8H through 9H is paralleled by an increase of the ratio of spumellaria and cryptocephalic nasselaria to elongated nasselaria. The presence of Albian to Cenomanian taxa and the absence of typical Cenomanian forms as observed farther upsection suggest a late Albian age of the fauna. The known range from *Alievum sculptus* and *Novixitus mclaughlini* is middle Albian to Cenomanian, *Cavaspongia sphaerica* has been observed in late Albian to Turonian sediments, and *Obiculiforma maxima* is recorded from the late Aptian to Turonian. The co-occurrence of these taxa with *Pseudodictyomitra lodogaensis* that has a well-established range from the late Aptian to late Albian indicates a late Albian age of this interval. In Tethyan and North Atlantic sections, *P. lodogaensis* has not been observed in sediments younger than the late Albian *Rotalipora ticinensis* planktonic foraminifer zone. The known first occurrence of *C. sphaerica* lies within the same zone. This might indicate a middle late Albian (*R. ticinensis* planktonic foraminifer zone, *Pseudodictyomitra pseudomacrocephala* radiolarian zone, Erbacher and Thurow, in press) age for Cores 159-162B-9H through 10H. If the upper part for Core 159-962B-9H is middle-late Albian in age, this would imply that the Vraconian is either very reduced or missing. No clear Vraconian faunal elements have been identified in samples from Core 159-162B-8H. Again, the observed fauna shows numerous signs of an endemic character. The lack of typical forms and a comparably very low diversity (in general, late Albian faunas are characterized by remarkably high diversities, (Erbacher and Thurow, 1997), together with a dominance of spumellaria and cryptocephalic nasselaria clearly distinguishes this fauna from time-equivalent Tethyan assemblages.

## PALEOBIOGEOGRAPHY AND PALEOCEANOGRAPHY

Mid-Cretaceous radiolarians of Hole 962B add some interesting insights into the opening of the Equatorial Atlantic Gateway and general radiolarian paleobiogeography. The first faunal migrations, as a



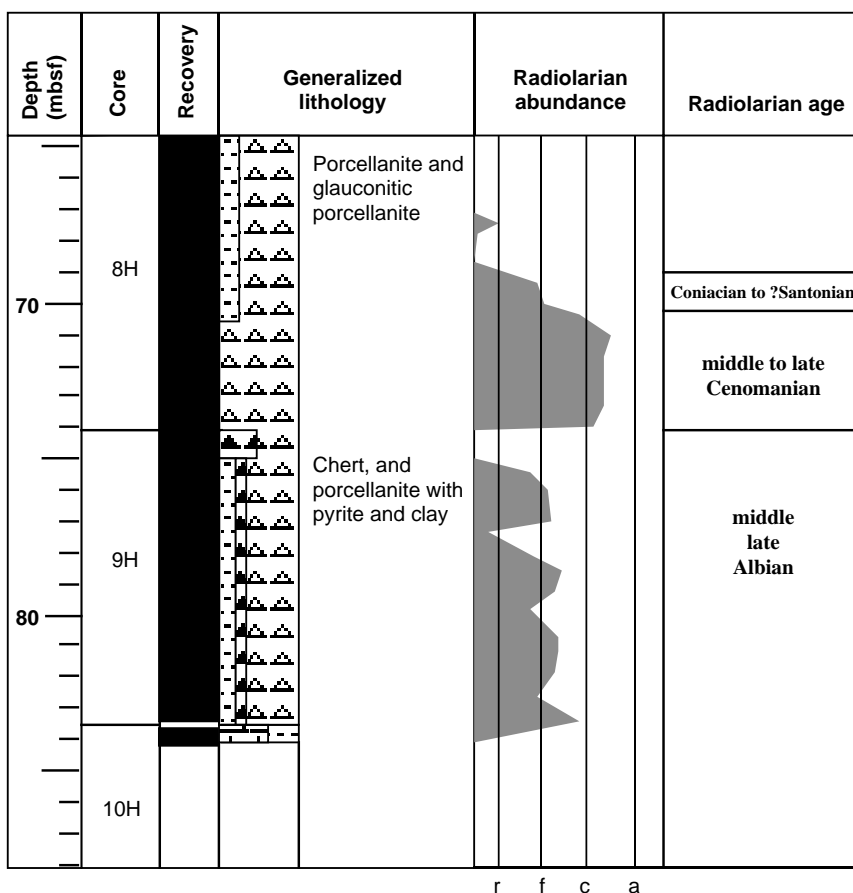


Figure 2. Radiolarian biostratigraphy and radiolarian abundance summary of the late Albian to ?Santonian interval of Hole 962B. Indicated are sub-bottom depth, core recovery and lithology. Radiolarian abundances are divided into r (rare) = <20 radiolarians per 10 cm<sup>3</sup>, f (few) = <50 radiolarians per 10 cm<sup>3</sup>, c (common) = <80 radiolarians per 10 cm<sup>3</sup>, and a (abundant) = >80 radiolarians per 10 cm<sup>3</sup>. See biostratigraphy section of this chapter for tentative mid-Cretaceous radiolarian zonation of Hole 962B. Graphic lithology modified after the “Principal Results” chapter, Shipboard Scientific Party (1996).

result of the opening of the gateway, are documented from the middle Albian by ammonites and planktonic foraminifers (Wiedmann and Neugebauer, 1978; Moullade et al., 1993). However, recently, Bonatti et al. (1996) documented Berriasian Maiolica-type limestones dated by Calpionellids that resemble Tethyan assemblages. These occurred in the Romanche fracture zone, which lies in the southwestward elongation of Site 962. Even if the paleogeographic position of these limestones remains difficult, it might indicate a first marine ingression within the area of the Equatorial Atlantic Gateway as early as the earliest Cretaceous (Bonatti et al., 1996).

During Leg 159, no marine sediments older than Albian were drilled (Shipboard Scientific Party, 1996). Late Albian to Cenomanian radiolarian faunas are of a remarkably low diversity, compared to time-equivalent assemblages from the Tethys, North Atlantic, and Pacific. Some of the observed species are appearing in a completely different range than described before (*Theocampe apicata*, *Cryptamphorella crepida*, *Cromyodruppa ?concentrica*, see taxonomic notes). It is difficult to explain this with an endemism and/or an influence of cold austral water masses. However, an increase of the diversity and average size of the tests in combination with an increase of the number of Tethyan taxa can be observed from Cores 159-962B-8H through 9H, which can be interpreted as a result of an ongoing opening of the gateway between the North and South Atlantic. Considering the morphotypes at Hole 962B, it is obvious that many elongated nassellarians (e.g., *Pseudodictyomitra*, *Xitus*, *Novixitus*, *Torculum*, *Obeliscoides*) as well as most of the hagiastrid spumellarians (*Halesium*, *Patulibracchium*, *Paronella*) are lacking or underrepresented. Forms with a spongy test like *Archaeospongoprimum*, *Orbiculiforma*, *Cavaspongia*, *Cromyodruppa*, and *Dactyliosphaera* dominate, especially the Cenomanian assemblages. The late Albian is dominated by cryptocephalic nassellarians (e.g., *Cryptamphorella*).

“Spongy” radiolarians are also an important part of the radiolarian assemblages described from the late Albian and Cenomanian of the Great Valley Sequence in California (Pessagno, 1976, 1977), but are somewhat underrepresented in the Deep Sea Drilling Project (DSDP) sites from the North Atlantic (Thurrow, 1988; Erbacher, 1994). Whether this indicates an influence of Pacific faunas and water masses in the South Atlantic remains very questionable. Up to now, too little knowledge about mid-Cretaceous austral assemblages exists to discuss the influences of different faunal provinces on the assemblages of the South Atlantic.

As mentioned above, the percentage of taxa of a clearly Tethyan origin increases toward the late Cretaceous. It would be speculative to discuss the mechanisms of the selection of species migrating into the southern Atlantic. However, if Tethyan forms occur in the eastern equatorial Atlantic, an exchange of Tethyan and South Atlantic water masses must have existed since the late Albian (middle Albian?). A certain degree of endemism could then be explained by a connection of the South Atlantic to Tethyan/North Atlantic water masses at distinct time slices, possibly controlled by sea-level and/or tectono-eustatic movements within the gateway (Shipboard Scientific Party, 1996). Restricted circulation in the equatorial Atlantic basins in times of limited exchange with northern oceans would then lead to endemism. The first observed Tethyan ammonites (Wiedmann and Neugebauer, 1978) and hedbergellids (Moullade et al., 1993) appearing in the South Atlantic are interpreted to be shallow dwellers (Hart, 1980), an argument which would favor the sea-level theory.

Another potential factor responsible for the endemic character of the fauna could be a lower temperature that controlled the absence of many Tethyan taxa in the late Albian. This factor would also explain the limited average size of the late Albian assemblage. Whereas the global temperature gradients toward the Cenomanian/Turonian (e.g.,

Frakes et al., 1992; Barron and Washington, 1984) decreases, the influence of Tethyan elements increases.

It follows that stratigraphic levels at which radiolarians are frequent in the mid-Cretaceous section of Hole 962B correlate well with time-equivalent radiolarian events in other basins (Thurrow, 1988; Erbacher and Thurow, 1997). These time intervals are the late Albian (pre-OAE 1d) and the late Cenomanian (pre-OAE 2). Both time intervals are characterized by signs of global sea-level rise and transgressions as well as high abundances and diversities of radiolarians (e.g., Haq et al., 1987; Erbacher et al., 1996). In pelagic environments, the time of highest sea-level/maximum flooding of these transgressive events is represented by black shale levels (so-called oceanic anoxic events; Jenkyns, 1980; Arthur et al., 1990; Erbacher et al., 1996). It is interesting that neither the Vraconian (with OAE 1d) nor the Cenomanian/Turonian Boundary (OAE 2) is recorded in sediments from Hole 962B. This is interpreted as an indication that the paleo-position of Hole 962B lay on a structural high. These hiatuses can be induced by increased bottom currents resulting from the opening of the equatorial gateway, accompanied by changes of circulation patterns. A simple continuing rise of sea level could have similar effects if swell-like structures, which must have existed within the transform system (Shipboard Scientific Party, 1996), played the role of a barrier during times of relatively low sea level.

Another correlation worthy of note is the parallel between radiolarian-rich intervals and the appearance of the clay mineral palygorskite, discussed at length by Pletsch (Chap. 15, this volume).

## CONCLUSIONS

Mid-Cretaceous sediments drilled during ODP Leg 159 reveal three intervals containing radiolarians. These intervals are of ?Coniacian to Santonian (159-962B-8H-4, 2–28 cm), middle to late Cenomanian (159-962B-8H-4, 85 cm, to 8H-CC), and middle late Albian (159-962B-9H to 10H-CC) age. These assemblages are characterized by different preservations, diversities, and average test sizes.

Late Albian to Cenomanian radiolarian faunas show signs of Tethyan faunal influences, but show little diversity. Some of the observed forms differ from relatives from the North Atlantic/Tethys that, together with the small growth of the middle-late Albian fauna and the observed low diversity, are interpreted as signs of endemism. This endemism is discussed as resulting from restricted circulations in the eastern equatorial Atlantic basins and sea-level dependent connection to water masses from the North Atlantic and/or resulting from latitudinal temperature gradients between Tethyan and Austral water masses.

Radiolarian-bearing intervals correlate well with global radiolarian-rich intervals typical for transgressive time periods preceding mid-Cretaceous OAE. Possible hiatuses in the uppermost Albian (Vraconian) and around the Cenomanian/Turonian boundary indicate that the paleo-position of Hole 962B is on a structural high.

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## APPENDIX

### Taxonomic Notes

Radiolarians are listed in alphabetic order. The listed references refer to either the original and/or other relevant descriptions of the described species. Where appropriate, an explanatory text and the stratigraphic range of the taxa are added. See O'Dogherty (1994) or Erbacher (1994) for more complete synonyms and reference list.

#### *Acaeniotyle diaphorogona* (Foreman)

*Acaeniotyle diaphorogona* Foreman, 1973, p. 258, pl. 2, figs. 2–5.

*A. diaphorogona* has been described from the Early Cretaceous to early Turonian, worldwide.

#### *Acaeniotyle amplissima* (Foreman) (Pl. 2, Fig. 21)

*Acaeniotyle florea*, Ozvoldova and Petercakova, Erbacher, 1994, p. 90, pl. 11, fig. 10.

*Acaeniotyle amplissima* (Foreman), O'Dogherty, 1994, pp. 288–289, pl. 51, figs 11–14.

*A. amplissima* has been described from the Aptian to early Turonian of the North Atlantic and western Tethys.

#### *Acaeniotyle umbilicata* (Rüst) (Pl. 2, Fig. 19)

*Acaeniotyle umbilicata* (Rüst), Foreman, 1973, p. 258, pl. 1, figs. 13, 14, 16.

*Acaeniotyle* with two polar spines. The strongly developed tubercles and short spines lead me to place this form into *A. umbilicata* (see discussion in O'Dogherty, 1994)

#### *Acanthocircus* aff. *multidentatus* ? (Squinabol) (Pl. 2, Fig. 22)

*Acanthocircus multidentatus* (Squinabol), Pessagno, 1977, p. 32, pl. 3, figs. 15, 20; O'Dogherty, 1994, p. 255, pl. 44, figs. 7–10.

Since only fragments have been observed in samples of Hole 962B, a clear placement of these forms to *A. multidentatus* is questionable. The range of this form is not well established, mid-Cretaceous.

#### *Alievum sculptus* (Squinabol) (Pl. 2, Fig. 16)

*Alievium antiquum*, Pessagno, 1972, p. 298, pl. 24, figs. 1–4; Erbacher, 1994, pp. 90–91, pl. 12, fig. 1.

*Pseudoaulophacus sculptus* (Squinabol), O'Dogherty, 1994, pp. 319–320, pl. 59, figs. 1–4.

*A. sculptus* has been recorded from the middle Albian to Cenomanian of the Central Pacific, California, North Atlantic, and Central Italy.

#### *Angulobracchia digita* (Baumgartner) (Pl. 2, Fig. 27)

*Angulobracchia digita*, Baumgartner, 1980, pp. 310–312, pl. 10, figs. 18–22, pl. 12, fig. 11; Erbacher, 1994, p. 92, pl. 5, figs. 5 and 6.

Only one single specimen was observed in Sample 159-962B-8H-6, 137–141 cm. *A. digita* has been described from the Middle to Late Jurassic of Greece (Baumgartner, 1980) and the early late Albian of the North Atlantic (Erbacher, 1994).

#### *Archaeodictyomitra crebrisulcata* (Squinabol) (Pl. 1, Fig. 10)

*Dictyomitra crebrisulcata* (Squinabol), O'Dogherty, 1994, p. 75, pl. 2, figs. 12–17.

*D. crebrisulcata* has been recorded from the middle Cenomanian to low-ermost Turonian of Central Italy.

#### *Archaeodictyomitra simplex* Pessagno (Pl. 1, Fig. 11)

*Archaeodictyomitra simplex*, Pessagno, 1977, p. 43, pl. 6, figs. 1, 24, 28, pl. 12, fig. 12; Thurrow, 1988, p. 398, pl. 3, fig. 9.

*Dictyomitra montisserei* (Squinabol), O'Dogherty, 1994, p. 77, pl. 3, figs. 1–29.

#### *Archaeospongoprimum carrierensis* (Pessagno) (Pl. 1, Fig. 22)

*Archaeospongoprimum carrierensis*, Pessagno, 1977, p. 29, pl. 1, figs. 6, 7, 9; Ellis, 1993, p. 958, pl. 3, figs. 3, 4.

Recorded from the late Aptian to late Albian of Western Australia and California. The range of this form is not yet well established.

#### *Archaeospongoprimum* sp. (Pl. 1, Figs. 23 and 29)

These forms, common in Albian and Cenomanian samples of Hole 962B, have an elongated, cylindrical test. One spine is triradiate, the other spiral. They resemble *A. triplum* (Pessagno, 1973) but lack distinct lobes. *A. triplum* has been described from the Coniacian of California.

#### *Cavaspongia euganea* (Squinabol) (Pl. 2, Fig. 24)

*Dumitricaia* sp. EJ 1, Erbacher, 1994, p. 98, pl. 12, fig. 6.

*Dumitricaia* sp. EJ 2, Erbacher, 1994, p. 98, pl. 12, fig. 5.

*Cavaspongia euganea* (Squinabol), O'Dogherty, 1994, p. 309, pl. 56, figs. 8–14.

The known range of *C. euganea* is late Albian to late Cenomanian (?early Turonian). The central part of the forms illustrated herein is less raised than with those from Central Italy.

*Cavaspongia sphaerica* O'Dogherty  
(Pl. 2, Fig. 23)

*Cavaspongia sphaerica*, O'Dogherty, 1994, p. 311, pl. 57, figs 1–7.

*C. sphaerica* is a common part of the assemblages from interval 159-962B-8H-4, 85 cm, through 8H-CC. A single specimen was observed in interval 159-962B-9H-2, 88–92 cm. The taxon has been described from the late Albian to Turonian of Central Italy. The forms observed in Core 159-962B-8H differ from those described by O'Dogherty (1994) in possessing a more inflated central area.

*Cromyodruppa ? concentrica* Lipmann  
(Pl. 2, Figs. 14–15)

*Cromyodruppa ? concentrica* Lipmann, Ling and Lazarus, 1990, p. 355, pl. 1, figs. 11–13.

This spongy species is one of the most common throughout all cores bearing Albian to Cenomanian radiolaria of Hole 962B. *C. ? concentrica* has been described from the Campanian to Maastrichtian of the Central Atlantic, Weddell Sea and Russia, but is of a late Albian age in the section examined herein.

*Crucella irwini* Pessagno  
(Pl. 2, Fig. 29)

*Crucella irwini*, Pessagno, 1971, p. 55, pl. 9, figs. 4–6; Erbacher, 1994, p. 96, pl. 18, fig. 5; O'Dogherty, 1994, p. 369, pl. 71, figs. 7–14.

*C. irwini* has been reported from Cenomanian to Turonian strata, worldwide.

*Crucella messinae* Pessagno  
(Pl. 2, Fig. 26)

*Crucella messinae*, Pessagno, 1971, p. 56, pl. 6, figs. 1–3.

*Cryptamphorella conara* (Foreman)  
(Pl. 2, Figs. 10–11)

*Hemicryptocapsa conara*, Foreman, 1968, p. 35, pl. 4, figs. 11a, b.  
*Cryptamphorella conara* (Foreman), (Dumitrica, 1970), p. 80, pl. 11, figs. 66a–c; 1972, p. 842, pl. 1, figs. 2–5; 1975, fig. 2, no. 28; Erbacher, 1994, p. 97, pl. 5, fig. 7.

*Cryptamphorella crepida* O'Dogherty  
(Pl. 2, Fig. 13)

*Cryptamphorella crepida*, O'Dogherty, 1994, p. 210, pl. 34, figs. 15–21.

The range of *C. crepida* has been described as early to middle Aptian (O'Dogherty, 1994) and has been described from the Pacific, North Atlantic and western Tethys. However, this form appears in the late Albian of Hole 962B which might again be a sign of endemism.

*Cryptamphorella* sp.  
(Pl. 2, Fig. 12)

This cryptothoracic form possesses a small elevated cephalis. The cephalis is perforate. No sutural pore was preserved on the very few observed specimens. Abdominal wall thickened by nodes. Nodes are connected by crests, building polygonal areas.

*Dactyliosphaera silviae* Squinabol  
(Pl. 1, Fig. 27)

*Pseudoaulophacus ?* sp. D, Thurow, 1988, p. 404, pl. 5, fig. 14; Erbacher, 1994, p. 109, pl. 12, fig. 13, pl. 16, fig. 14.  
*Dactyliosphaera silviae* Squinabol, O'Dogherty, 1994, p. 341, pl. 63, figs. 22–26.

*D. silviae* is the nominal species of O'Dogherty's (1994) Silviae-Zone, ranging from late early Cenomanian to late Cenomanian. However, this form has been described from middle Albian to Cenomanian sediments of the North Atlantic (see Erbacher, 1994).

*Dactyliosphaera lepta* (Foreman)  
(Pl. 1, Fig. 28)

*Amphibrachium leptum*, Foreman, 1978, p. 841, pl. 1, figs. 8 and 9.  
*? Spongodruppa* sp. EJ 1, Erbacher, 1994, p. 113, pl. 13, fig. 3.  
*Dactyliosphaera lepta*, O'Dogherty, 1994, p. 340, pl. 63, figs. 13–21

*D. lepta* is one of the characteristic forms of interval 159-962B-8H-4, 85 cm, to 8H-CC. The species has been described from the late Albian to early late Cenomanian of Central Italy and the North and South Atlantic. Compared to Tethyan occurrences, *D. lepta* in the material investigated herein lacks a well-developed rise of the central cavity.

*Dicroa rara* (Squinabol)  
(Pl. 2, Fig. 18)

*Dicroa rara* (Squinabol), O'Dogherty, 1994, pp. 281–282, pl. 49, figs. 26–30.

This species has been described from the late Albian to lowermost Turonian of the western Tethys.

*Dictyomitra densicostata* Pessagno  
(Pl. 1, Fig. 4)

*Dictyomitra densicostata*, Pessagno, 1976, p. 51, pl. 14, figs. 10–14, 16.

This form has been described from the Campanian of California.

*Dictyomitra multicostata* Zittel  
(Pl. 1, Fig. 5)

*Dictyomitra multicostata* Zittel, O'Dogherty, 1994, p. 82, pl. 4, figs. 17–19.

*D. multicostata* has been described from early Turonian to Campanian (Maastrichtian?), worldwide.

*Dictyomitra napaensis* Pessagno  
(Pl. 1, Fig. 3)

*Dictyomitra napaensis*, Pessagno, 1976, p. 53, pl. 4, fig. 16, pl. 5, figs. 1, 9.

*D. napaensis* has been described from the late Turonian to late Coniacian of California.

*Guttacapsa biacuta* (Squinabol)  
(Pl. 1, Fig. 15)

*Guttacapsa biacuta* (Squinabol), O'Dogherty, 1994, p. 226, pl. 37, figs. 31–35.

*G. biacuta* is the nominal species of the biacuta subzone (O'Dogherty, 1994), uppermost Cenomanian of Central Italy.

*Guttacapsa gutta* (Squinabol)  
(Pl. 1, Fig. 8)

*Guttacapsa gutta* (Squinabol), O'Dogherty, 1994, pl. 38, figs. 1–6.  
*G. gutta* has been described from the late Cenomanian of Central Italy and Japan.

*? Hiscocapsa* sp.  
(Pl. 1, Figs. 19–20)

This form is a common part of the Cenomanian assemblage of the investigated core. As any ornamentation on the large globose, open, terminal chamber is lacking, this form is only tentatively placed within the genus *Hiscocapsa*. The examined forms lack an apical horn; their cephalis is small, smooth, and round. The distal chamber possesses an aperture.

?*Krempelinella* sp.  
(Pl. 1, Fig. 7)

The genus *Krempelinella* has been defined by Empson-Morin (1981). Following her, *Krempelinella* resembles Neosciadiocapsidae and is closely related to the genus *Rhopalosyringium*.

The type species of this genus *K. kronenartiga* has been described from the Campanian of the Central Pacific.

*Mita gracilis* (Squinabol)  
(Pl. 1, Fig. 13)

*Mita gracilis* (Squinabol), Thurow, 1988, p. 402, pl. 3, fig. 2., Erbacher, 1994, p. 102, figs. 10 and 11.

*Dictyomitra gracilis* (Squinabol), O'Dogherty, 1994, p. 73, pl. 1, figs. 12–25. *M. gracilis* has been described from the Albian to early late Cenomanian worldwide.

*Napora praespinifera* (Pessagno)  
(Pl. 1, Fig. 21)

*Napora praespinifera*, Thurow, 1988, p. 402, pl. 5, fig. 3, Erbacher, 1994, p. 103, pl. 9, fig. 8, pl. 13, fig. 8.

*Ultranapora praespinifera* Pessagno, 1977, p. 39, pl. 5, figs. 4, 8–10, O'Dogherty, 1994, p. 241, pl. 41, figs. 15–23.

*Novixitus mclaughlini* Pessagno  
(Pl. 2, Fig. 6)

*Novixitus mclaughlini*, Pessagno, 1977, p. 54, pl. 9, fig. 17; Thurow, 1988, p. 402, pl. 3, fig. 21; Erbacher, 1994, p. 104, pl. 6, fig. 4, pl. 7, figs. 13–14.

This species has been recorded from the Albian to Cenomanian of California, North Atlantic and western Tethys.

*Orbiculiforma maxima* Pessagno  
(Pl. 1, Fig. 25)

*Orbiculiforma maxima*, Pessagno, 1976, pp. 34–35, pl. 1, fig. 14, 16  
*Orbiculiforma railensis* Pessagno, Thurow, 1988, p. 403, pl. 5, fig. 18.  
*Orbiculiforma* sp. EJ2, Erbacher, 1994, p. 105, pl. 2, figs. 7–8

*Dactylosphaera maxima* (Pessagno), O'Dogherty, 1994, pp. 338–339, pl. 63, figs. 5–8.

non *Orbiculiforma maxima* Pessagno, Erbacher, 1994, pp. 104–105, pl. 13, figs. 5–6.

*O. maxima* has been described from the late Aptian to Cenomanian of Central Italy, North Atlantic, California, and Pacific.

*Orbiculiforma* sp.  
(Pl. 2, Fig. 17)

This form is a common part of radiolarian assemblages from the late Albian of the investigated core.

*Patellula heroica* O'Dogherty  
(Pl. 1, Fig. 26)

*Patellula heroica*, O'Dogherty, 1994, p. 330, pl. 61, figs. 6–11.

*P. heroica* has been described from the early Turonian of Central Italy.

*Patellula verteroensis* (Pessagno)  
(Pl. 1, Fig. 24)

*Stylospongia verteroensis* Pessagno, 1963, p. 199, pl. 3, figs. 1–3, pl. 6, figs. 2, 3, pl. 7, figs. 3, 6.

*Patellula verteroensis*, Erbacher, 1994, p. 106, pl. 19, figs. 1–2; O'Dogherty, 1994, pp. 328–329, pl. 60, figs. 25–26.

*P. verteroensis* has been described worldwide from the late Cenomanian to Campanian.

*Patulibracchium* sp.  
(Pl. 2, Fig. 25)

As only one to two rays are preserved in the forms examined in this study; a clear identification of these forms on a species level is impossible. Hagistrid radiolarians are remarkably rare in Cretaceous faunas from Hole 962B.

*Pseudodictyomitra lodogaensis* Pessagno  
(Pl. 2, Fig. 4)

*Pseudodictyomitra lodogaensis*, Pessagno, 1977, p. 50, pl. 8, figs. 4, 21, 28; Ellis, 1993, p. 969, pl. 4, fig. 18; Erbacher, 1994, pp. 109–110, pl. 8, figs. 1–2, O'Dogherty, 1994, pp. 103–104, pl. 7, figs. 18–21.

This form has been reported from the late Aptian to late Albian, worldwide.

*Rhopalosyringium hispidum* O'Dogherty  
(Pl. 1, Fig. 6)

*Rhopalosyringium hispidum*, O'Dogherty, 1994, p. 167, pl. 23, figs. 7–11.

*R. hispidum* has been described from the early Turonian of Central Italy.

*Rhopalosyringium mosquense* (Smirnova and Aliev)  
(Pl. 2, Fig. 8)

*Rhopalosyringium majuroensis* Schaaf, Thurow, 1988, p. 405, pl. 4, fig. 15; Erbacher, 1994, p. 111, pl. 9, fig. 5.

*Rhopalosyringium mosquense* (Smirnova and Aliev), O'Dogherty, 1994, pp. 165–166, pl. 22, figs. 1–6.

*R. mosquense* has been described from the late Albian of the North Atlantic and late Albian to late Cenomanian of the western Tethys.

*Rhopalosyringium* sp. cf. *R. euganeum* (Squinabol)  
(Pl. 1, Fig. 18)

The form described herein differs from *R. euganeum*, illustrated in O'Dogherty (1994) and as *Rhopalosyringium* sp. C in Thurow (1988) and Erbacher (1994), by lacking an apical horn, by lacking clear strictures, and by being more slender. *R. aff. R. euganeum* is rare but occurs in every sample that has been investigated of interval 159-962B-8H-4, 85 cm, through 8H-CC, as well as in some samples of Cores 159-962B-9H through 10H.

*Savaryella quadra* (Foreman)  
(Pl. 2, Fig. 28)

*Crucella quadra*, Foreman, 1978, p. 841, pl. 1, fig. 10.

*Savaryella quadra* (Foreman), O'Dogherty, 1994, p. 372, pl. 72, figs. 1–11.

*S. quadra* has been recorded from the late Albian to middle Cenomanian of the South Atlantic and Central Italy.

*Stichomitra communis* Squinabol  
(Pl. 1, Fig. 12)

*Stichomitra communis*, Squinabol, 1903, p. 141, pl. 8, fig. 40.

This common species has been reported from the late Aptian to Turonian, worldwide.

*Stichomitra stocki* (Campbell and Clark)  
(Pl. 1, Fig. 14, Pl. 2, Fig. 1)

*Stichocapsa* (?) *stocki*, Campbell and Clark, 1944, p. 44, pl. 8, figs. 31–33.  
*Amphipyndax stocki* (Campbell and Clark), Foreman, 1968, p. 78, pl. 8, figs. 12a–c.

*Amphipyndax mediocris* (Tan Sin Hok), Erbacher, 1994, pp. 91–92, pl. 6, figs. 1–2.

*Stichomitra stocki* (Campbell and Clark), O'Dogherty, 1994, pp. 147–148, pl. 18, figs. 9–15.



*Stichomitra stocki* has been described from the middle Cenomanian to Campanian almost worldwide. The confusion about former *Amphipyndax stocki* and *A. mediocris* has been cleared by O'Dogherty (1994) who observed that both forms are homeomorph, but clearly separated by a disconnected stratigraphic range at least in the Central Italian sections he examined. However, the late Albian forms of *S. stocki* as illustrated herein (Pl. 1, Fig. 14, and Pl. 2, Fig. 1) clearly resemble O'Dogherty's (1994) *S. stocki* even that they appear in the late Albian, which should be after O'Dogherty (1994) within the range of *S. mediocris*.

*Theocampe apicata* Foreman  
(Pl. 2, Fig. 5)

*Theocampe apicata*, Foreman, 1971, p. 1679, pl. 4, fig. 6; Empson-Morin, 1981, p. 262, pl. 7, figs. 1a–2d.

This tiny species appears in two samples of Core 159-962B-9H. To my knowledge it has not been described from sediments older than Campanian, but is of a late Albian age in the section examined herein.

*Torculum coronatum* (Squinabol)  
(Pl. 1, Fig. 17)

*Theoconus coronatus* Squinabol group, Erbacher, 1994, p. 116, pl. 7, fig. 6, pl. 14, figs. 4–5, pl. 15, figs. 12–13.  
*Theoconus* spp. group, Erbacher, 1994, p. 116, pl. 7, figs. 7–10, pl. 14, fig. 6.  
*Torculum coronatum* (Squinabol), O'Dogherty, 1994, p. 133, pl. 12, figs. 27–28, pl. 14, figs. 1–29.

This species is of an incredible morphological variance. It ranges from the middle Albian to early late Cenomanian and has been described worldwide.

*Tubilustrium* sp. aff. *T. transmontanum* O'Dogherty  
(Pl. 1, Fig. 16)

The described specimens lack the strongly compressed distal chamber of *T. transmontanum* (see O'Dogherty, 1994). *T. transmontanum* has been described from the late Albian to late Cenomanian of Central Italy.

*Triactoma* sp.  
(Pl. 2, Fig. 20)

This morphotype is rather frequent in almost all "Cenomanian" samples of the investigated core.

*Vitorfus morini* Empson-Morin  
(Pl. 1, Fig. 9)

*Vitorfus morini*, Empson-Morin, 1981, p. 261, pl. 4, figs. 7a–8d, O'Dogherty, 1994, pp. 267–268, pl. 47, figs. 12–15.

The specimen illustrated herein is rather poorly preserved. However, the spines are only bladed in the proximal parts and, therefore, clearly separate this form from the genus *Archaeospongoprimum*. *V. morini* has been described from the early Turonian to Campanian of Central Italy, the Pacific, and Japan.

*Xitus spicularius* (Aliev)  
(Pl. 1, Figs. 1–2)

*Xitus spicularius* (Aliev) - Pessagno, 1977, p. 56, pl. 9, fig. 7, pl. 10, fig. 5; Erbacher, 1994, p. 118, pl. 3, fig. 4, pl. 15, fig. 7; O'Dogherty, 1994, p. 127, pl. 11, figs. 17–31.

*X. spicularius* has been described from late Aptian to late Cenomanian deposits, worldwide. At Hole 962B, this species only appears in interval 159-962B-8H-4, 24–28 cm, which seems to be of a late Turonian to Santonian age. This form has also been observed in the Campanian of Cyprus (E. Urquhart, pers. comm., 1996).

*Xitus spinosus* (Squinabol)  
(Pl. 2, Fig. 3)

*Xitus spinosus* (Squinabol), O'Dogherty, 1994, pp. 129–130, pl. 12, figs. 1–13.

?*Xitus* sp. cf. *X. spicularius*  
(Pl. 2, Fig. 2)

This form is common in samples of Cores 159-962B-9H and 10H. It differs from *X. spicularius* by lacking the outer layer and therefore only showing the inner layer with small uniform pore frames. Most of the observed specimens have less than five post abdominal chambers. As the forms examined herein resemble a specimen of *X. spicularius* illustrated in O'Dogherty, 1994 (pl. 11, fig. 23) they have tentatively been placed within this species. This species is considered as another sign for endemism in the late Albian of the Eastern Equatorial Atlantic.

gen. et sp. indet 1  
(Pl. 2, Fig. 7)

A rare, tiny species that has only been observed in two samples of Cores 159-962B-9H and 10H.

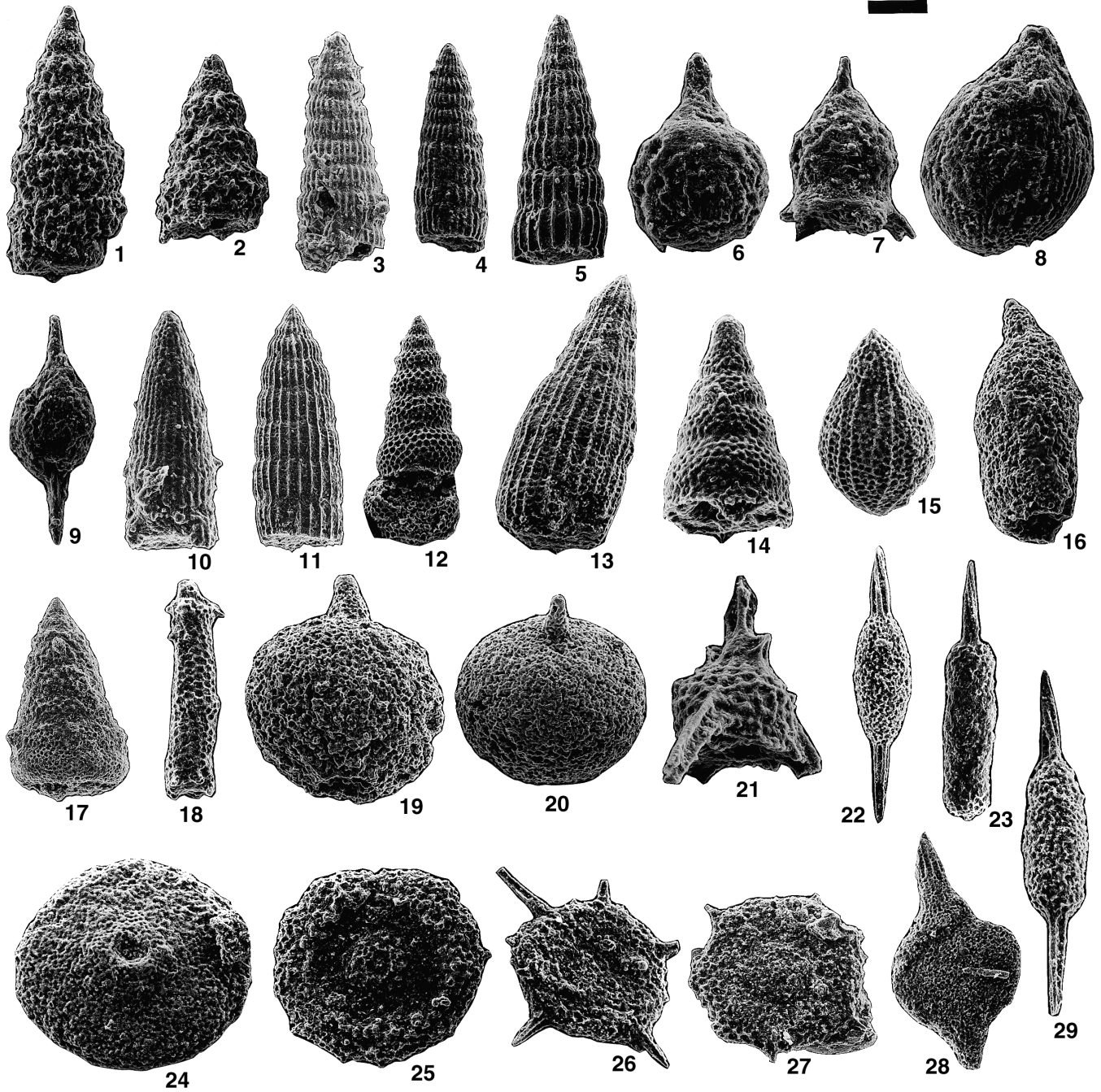


Plate 1. Scale bar = 40  $\mu\text{m}$  for Figures 10, 14, 6, and 21; 50  $\mu\text{m}$  for Figures 8, 29, 7, and 15; 65  $\mu\text{m}$  for Figures 3, 26, 4, 1, 2, 13, and 9; 100  $\mu\text{m}$  for Figures 27, 11, 25, 28, 23, 18, 5, 22, 12, 16, 20, 24, and 19; and 200  $\mu\text{m}$  for Figure 17. Specimens illustrated in plate Figures 1 through 9 are from Sample 159-962B-8H-4, 24–28 cm. **1, 2.** *Xitus spicularius*. **3.** *Dictyomitra napaensis*. **4.** *Dictyomitra densicostata*. **5.** *Dictyomitra multicosata*. **6.** *Rhopalosyringium hispidum*. **7.** *?Krempeleinella* sp. **8.** *Guttacapsa gutta*. **9.** *Vitorfus morini*. **10.** *Archaeodictyomitra crebrisulcata* Sample 159-962B-8H-4, 85–86 cm. **11.** *Archaeodictyomitra simplex* Sample 159-962B-8H-5, 65–69 cm. **12.** *Stichomitra communis* Sample 159-962B-8H-6, 137–141 cm. **13.** *Mita gracilis* Sample 159-962B-8H-6, 137–141 cm. **14.** *Stichomitra stocki* Sample 159-962B-8H-4, 85–86 cm. **15.** *Guttacapsa biacuta* Sample 159-962B-8H-6, 137–141 cm. **16.** *Tubilastrum* sp. aff. *T. transmontanum* Sample 159-962B-8H-6, 137–141 cm. **17.** *Torculum coronatum* Sample 159-962B-8H-5, 65–69 cm. **18.** *Rhopalosyringium* sp. (cf. *R. euganeum*) Sample 159-962B-8H-CC, 14–16 cm. **19, 20.** *?Hiscocapsa* sp. Sample 159-962B-8H-6, 137–141 cm. **21.** *Napora praespinifera* Sample 159-962B-8H-6, 137–141 cm. **22.** *Archaeospongoprunum carrierensis* Sample 159-962B-8H-CC, 14–16 cm. **23.** *Archaeospongoprunum* sp. Sample 159-962B-8H-CC, 14–16 cm. **24.** *Patellula verteroensis* Sample 159-962B-8H-6, 137–141 cm. **25.** *Orbiculiforma maxima* Sample 159-962B-8H-6, 137–141 cm. **26.** *Patellula heroica* Sample 159-962B-8H-6, 137–141 cm. **27.** *Dactyliosphaera silviae* Sample 159-962B-8H-5, 34–36 cm. **28.** *Dactyliosphaera lepta* Sample 159-962B-8H-6, 137–141 cm. **29.** *Archaeospongoprunum* sp. Sample 159-962B-8H-6, 137–141 cm.

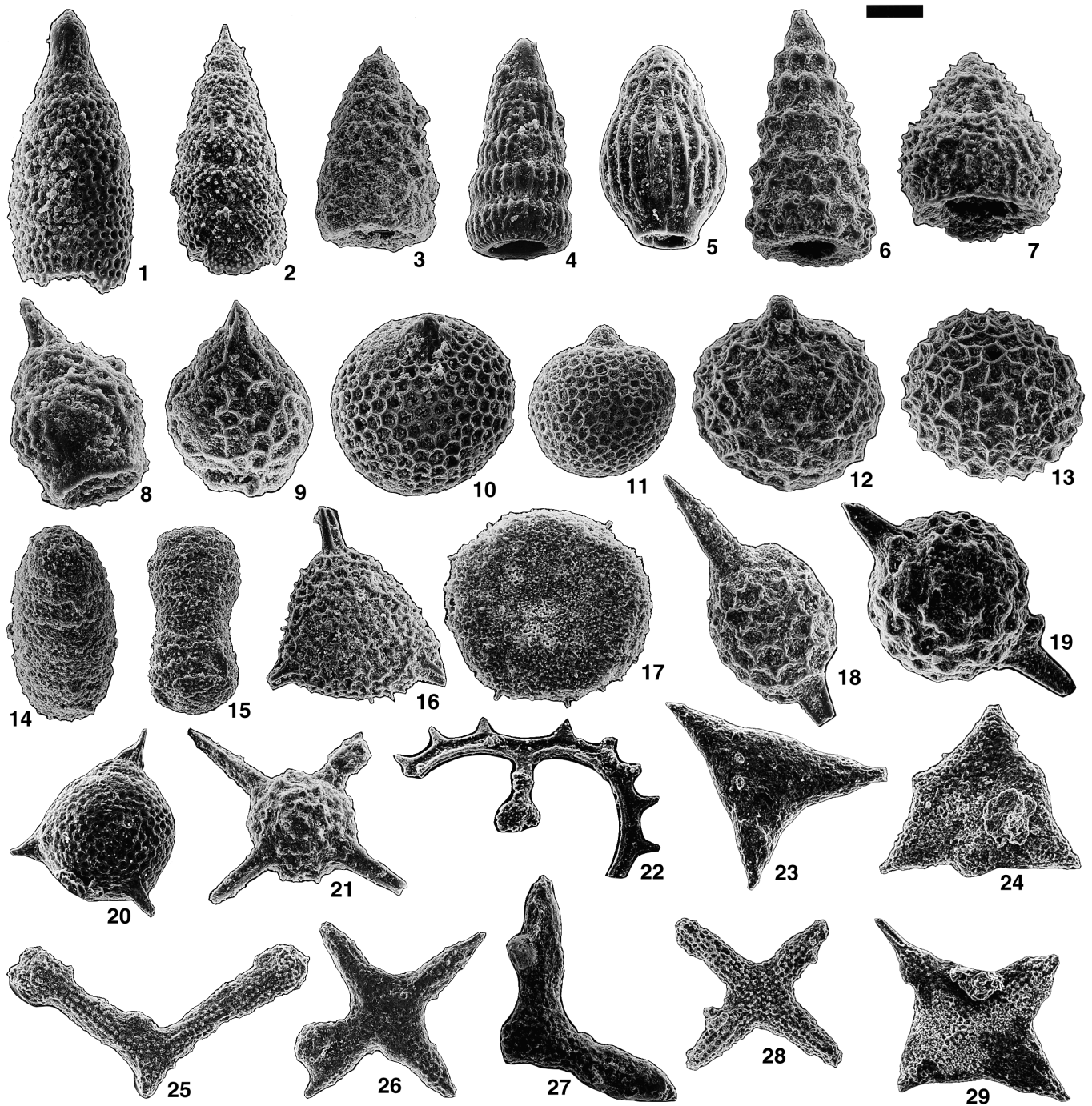


Plate 2. Scale bar = 40  $\mu$ m for Figures 1, 4, 5, 7, 8, 9, and 12; 50  $\mu$ m for Figures 2, 10, 11, 13, 18, 19, 20, and 21; 65  $\mu$ m for Figures 3, 16, 17, and 27; 100  $\mu$ m for Figures 6, 14, 15, 22, 23, 24, 26, 28, and 29; and 200  $\mu$ m for Figure 25. **1.** *Stichomitra stocki* Sample 159-962B-9H-CC, 11–13 cm. **2.** ?*Xitus* sp. cf. *X. spicularius* Sample 159-962B-9H-2, 88–92 cm. **3.** *Xitus spinosus* Sample 159-962B-10H-CC, 19–21 cm. **4.** *Pseudodictyomitra lodogaensis* Sample 159-962B-9H-2, 88–92 cm. **5.** *Theocampe apicata* Sample 159-962B-9H-2, 88–92 cm. **6.** *Novixitus mclaughlini* Sample 159-962B-10H-CC, 19–21 cm. **7.** gen. et sp. indet 1 Sample 159-962B-9H-2, 88–92 cm. **8.** *Rhopalosyringium mosquense* Sample 159-962B-9H-5, 142–146 cm. **9.** cryptocephalic nasselaria gen. et sp. indet Sample 159-962B-9H-2, 88–92 cm. **10.** *Cryptamphorella conara* Sample 159-962B-10H-CC, 19–21 cm. **11.** *Cryptamphorella conara* Sample 159-962B-9H-3, 36–40 cm. **12.** *Cryptamphorella* sp. Sample 159-962B-9H-6, 84–88 cm. **13.** *Cryptamphorella crepida* Sample 159-962B-9H-2, 88–92 cm. **14.** *Cromyodruppa* ? *concentrica* Sample 159-962B-9H-2, 88–92 cm. **15.** *Cromyodruppa* ? *concentrica* Sample 159-962B-9H-6, 84–88 cm. **16.** *Alievum sculptus* Sample 159-962B-10H-CC, 19–21 cm. **17.** *Orbiculiforma* sp. Sample 159-962B-9H-2, 88–92 cm. **18.** *Dicroa rara* Sample 159-962B-9H-3, 36–40 cm. **19.** *Acaeniotype umbilicata* Sample 159-962B-8H-4, 85–86 cm. **20.** *Triactoma* sp. Sample 159-962B-8H-4, 85–86 cm. **21.** *Acaeniotype amplissima* Sample 159-962B-8H-6, 80–84 cm. **22.** *Acanthocircus* aff. *multidentatus* Sample 159-962B-8H-6, 137–141 cm. **23.** *Cavaspongia sphaerica* Sample 159-962B-8H-4, 85–86 cm. **24.** *Cavaspongia euganea* Sample 159-962B-8H-4, 85–86 cm. **25.** *Patulibracchium* sp. Sample 159-962B-8H-6, 80–84 cm. **26.** *Crucella messinae* Sample 159-962B-8H-5, 65–69 cm. **27.** *Angulobracchia digita* Sample 159-962B-8H-6, 137–141 cm. **28.** *Savaryella quadra* Sample 159-962B-8H-5, 34–36 cm. **29.** *Crucella irwini* Sample 159-962B-8H-CC, 14–16 cm.